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Emission spectroscopy investigations on the low voltage circuit breaker

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The vacuum arc plasma produced during the electrode separation in the low voltage circuit breaker has been investigated by time resolved emission spectroscopy. The paper presents preliminary results concerning the influence of an axial magnetic field on the diffuse arc plasma. Some results of investigations on arc interruption failures in the constricted mode are also presented.

1. INTRODUCTION

The information concerning arc plasma parameters that lead to the successful or unsuccessful current interruption process is important for the technical improvement of the vacuum circuit breakers. Relating to the electrode activity and optical shape of the arc column, three main modes in the vacuum electric arc are developing: diffuse, columnar and constricted. In the case of nominal regime of the electrical network for the currents up to 4 kA (diffuse mode of the arc), the interruption is always successful after the first half-period current arcing time. For the overload and short circuit regimes (columnar and constricted modes of the arc) and currents higher than 10 kA, the current interruption could be successful, partially unsuccessful (the interruption occurs only after the second half period arching time) or totally unsuccessful (the interruption is not possible).

In this paper we present the results of the diagnostic by time-resolved emission spectroscopy of the vacuum arc plasma generated during electrode separation of a real vacuum circuit breaker. The investigations were focused on the diffuse and constricted modes, in the cases of nominal and short circuit regimes.

2. EXPERIMENTAL SET UP

The experimental set-up, reproducing exactly the conditions in a low voltage electrical network, was presented in a previous paper [1]. A stainless steel vacuum chamber with classical Cu-Cr50 electrodes (30 mm diameter, 3.5 mm gap) was used. In this structure, a variable axial magnetic field (AMF) up to 100 mT/kA was produced using Helmholtz type coils.

The test current simulates the rating current (1÷4 kA) and the short circuit current (10÷50 kA). Also, an imposed asymmetrical degree and adjustable half-period of the testing current can be provided by the electrical supply unit. The arcing moment can be set within ~500 μ s error using an ultra fast electro-mechanical device, based on Thompson electrodynamic effect. The half-period of the current was set at 16 ms. The vacuum chamber pressure was always 10^{-7} ÷ 10^{-8} mbar.

Time-resolved emission spectroscopy was performed using an Acton SP750 spectrograph coupled to a gated micro-channel plate (MCP) intensified CCD detector (512×512 pixels). A bundle of 19 optical fibers, placed in a single column, matched the spectrograph entrance. The opposite end of the bundle with circularly disposed fibers collected the arc light, for different positions of the arc column sampled using a multiple slit collimator (parallel splitter plates of 680 mm length, 2 mm apart). A number of 16 MCP gates per single shot were recorded, with the gate width of 500 μ s.

The measurements were performed in a wide spectral range (350-750 nm), and finally were focused on two spectral ranges, centered on 385 and 515 nm, where experimental lines were observed and also atomic data for Cr and Cu lines could be found.

3. RESULTS AND DISCUSSION

The influence of the AMF of about 820mT on the arc emission was analyzed. The typical time-resolved spectra for 3.4 kA arc current, with and without AMF, are presented in Fig. 1. The spectra are showing a change in plasma chemical composition during the arc evolution, less prominent in the presence of the axial magnetic field.

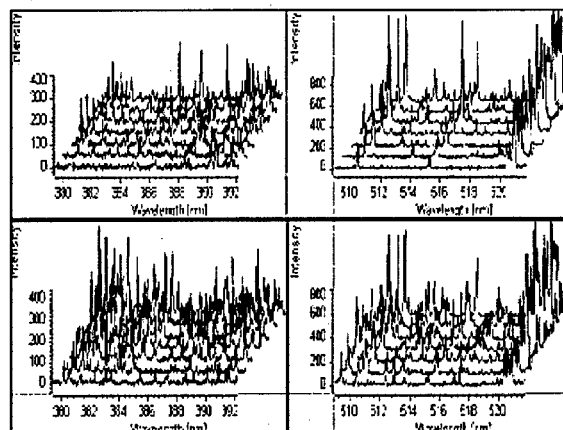


Fig.1 Time-resolved spectra - time as the third dimensions (AMF in the lower pictures)

This behavior is the result of the multiple particle jets production at the cathode, combined with the fast movement and short lifetime of the cathode spots during the arc. The jets dispersion is lower when an AMF is applied, which collimates the jets of charged particles around the electrode axis. Application of the magnetic field causes an enhanced excitation and ionization of the Cu and Cr atoms, by the trapped electrons, compared with the absence of the magnetic field. The presence of the AMF leads to a lower resistivity in the arc column, meaning lower energy dissipation in the plasma and lower contacts erosion.

Spectroscopic diagnosis was used to determine the excitation temperature of the atomic and ionic species using Boltzman graph method. Preliminary results on the diffuse mode regime showed a lower temperature than expected, of about 7000 K [2]. Data processing for different moments of the arc evolution revealed that Boltzman plot of the line intensities was not always a straight line. This led to the conclusion that the plasma in the diffusion mode is not in local thermodynamic equilibrium (LTE) [3],[4] and another method to characterize the diffuse mode plasma is necessary.

The experimental device has the ability to reproduce the behavior of a vacuum circuit breaker in real operation condition. This peculiarity allows to generate successful interruption, as well as partially unsuccessful interruptions as it is illustrated in Fig 2 in the case of constricted mode.

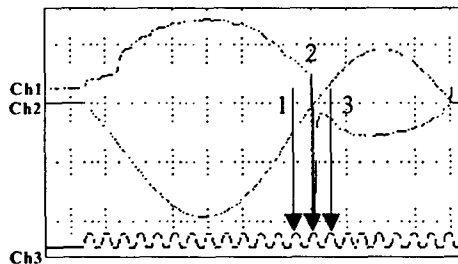


Fig. 2 Partially unsuccessful interruption 19.8 kA (Ch1: 20V/div; Ch2: 5 kA/div; Ch3: 10 V/div; 2ms/div)

Using single shot time resolved spectroscopy on partially unsuccessful interruption, in the case of 19 kA peak current, the evolution of the arc emission during the arcing was analyzed. The spectroscopic successive measurement shots around current zero (CZ) can be observed in Fig. 3 at different moments of the arc evolution, indicated by arrows on the CCD gate oscillogram (Fig. 2). As shown in Fig.3, Cu II ions (508.83, 509.38, 512.77 nm) are present in larger amounts after the arc reignition than Cr II, though the 50%Cu - 50%Cr electrodes composition. The observed higher CuII, in comparison with CrII, may be determined by their different ionisation threshold. With the assumption of LTE in the constricted mode, from spectroscopic data (neutral Cu lines 510.55, 515.32, 520.08, 521.28, 521.82 nm), plasma temperatures of 5800 – 7000⁰ K were estimated around CZ. These temperatures are not far from the plasma temperature in the high current arcing period. On this basis, it is

possible to conclude that the plasma, in a similar state as in the arcing time, was present between the electrodes in the moment of the CZ, providing the appropriate media for reignition. Near CZ the presence of a minimum charge density leading to the arc reignition is expected.

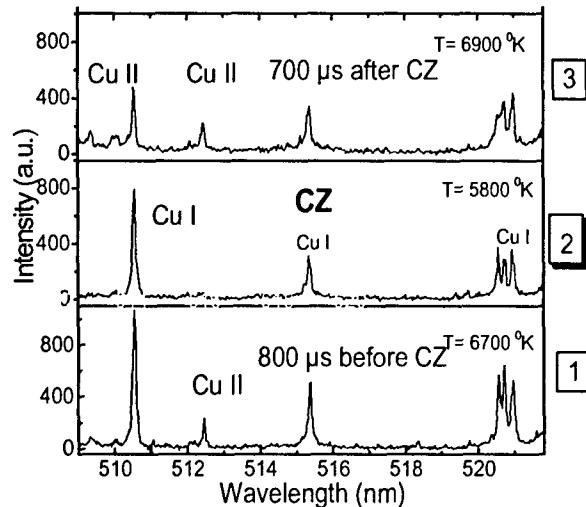


Fig. 3 Emission spectra around CZ

The measurements will be continued with absorption spectroscopy of the arc plasma in order to determine the plasma concentration around CZ and to establish the maximal value of the ion concentration for successful interruption.

4.CONCLUSIONS

Single shot time resolved emission spectroscopy of plasma in the low voltage vacuum circuit breaker for different working regimes revealed:

- Since the presence of the AMF stabilizes the arc plasma in the diffuse mode, a stronger effect is to be expected due to the higher values of the magnetic field (created by the current itself) in the constricted mode.
- Plasma temperature around CZ in partially unsuccessful interruption, approximately the same as in the arcing time, shows that the plasma is not sufficiently recombined, providing the appropriate media for reignition.

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